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(54) Wideband printed antenna system

(57) The present invention relates to a low-cost, wideband printed antenna system for the microwave and mm-wave frequency range. The antenna system according to the present invention consists of a butterfly-shaped dipole (radiator) comprising two elements 2, 3, balanced microstrip lines 4, 5 and balanced-to-unbalanced transition 8, 9 for the feeding network. The whole structure is printed on a low-loss dielectric substrate 1 and is placed about a quarter wavelength above a metal reflector plate 6. The two elements of the radiator are printed, respectively, on the opposite side of the substrate. Different radiating element shapes 5, 6 and their design method are presented. The proposed antenna system achieves wideband operation concerning impedance, antenna gain and radiation pattern characteristics. Bandwidth enhancement over the conventional dipole element, is achieved by the shape of the dipole, the proper matching between the feeding line and the radiating element, through coupling elements 10 located along the balanced microstrip lines and adjacent the radiating elements.

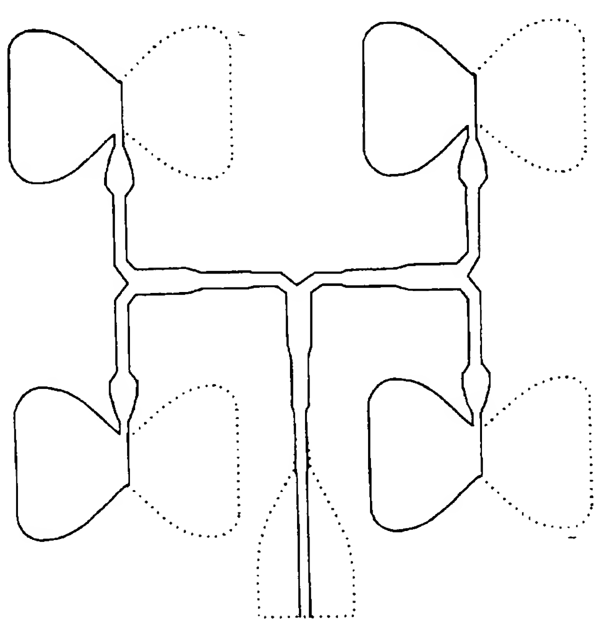

FIG. 11

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Description

[0001] The present invention relates to a wideband printed antenna system for the microwave and mm-wave frequency range. In particular the present invention relates to wideband printed antenna system for C band.

[0002] Microstrip antennas have become a fast evolving topic in antenna technology, mainly due to the increased need for miniaturization, integration with microwave integrated circuits and cost-effectiveness. However, when compared to traditional antenna elements, microstrip antennas have inferior electrical characteristics, one of them being the narrower operational bandwidth. The term *operational bandwidth* of an antenna refers to the radiation pattern (antenna gain, sidelobes level and cross-polarization) and impedance characteristics of the antenna. The need for wideband operation is a desirable characteristic especially for higher frequencies, because dimensional tolerances become critical, as they become comparable to the wavelength, and severely affect the antenna performance.

[0003] Research over the last decades has significantly improved the operational bandwidth of microstrip antennas over the traditional printed dipole, employing various techniques and antenna architectures. *U.S. Patent 4,847,625 (Dietrich et al)* describes a multilayer aperture-coupled microstrip antenna having bandwidth of about 20% with a VSWR of 2:1 or less. However, the complexity of multilayer structures results in increased cost and decreased ease of fabrication. *Yu-De Lin and Syh-Nan Tsai,* present in *"Analysis and Design of Broadside-Coupled Striplines-Fed Bow-tie Antennas", IEEE, March 1998,* a single-element bow-tie antenna fed by broadside-coupled striplines, which has a bandwidth of 19% for VSWR < 1.5:1. *U.S. Patent 6,037,911 (Brankovic et al)* describes a wideband printed phased array antenna having more than 30% working range compared to known microstrip dipole antennas. The document discloses an antenna with a plurality of single-element antenna systems, fed by a series of feeding lines, connected at T-junctions with particular features.

[0004] The object of the invention is a simple, single-element antenna system having the following characteristics: relatively increased wideband operation, low production costs, ease of fabrication, compact design, good efficiency, high gain, low tolerance sensitivity, multipurpose and mass-production capability

[0005] According to the invention the antenna system comprises a) a dielectric substrate with a front and a back dielectric face, b) a dipole with a first radiating element for radiating and receiving electromagnetic signals being printed on the front face of the dielectric substrate and a second radiating element for radiating and receiving electromagnetic signals being printed on the back face of the dielectric substrate, c) a metal strip for supplying signals to and from the dipole, said metal strip having a first line coupled to the first radiating element and a second line coupled to the second radiating element. Further, according to the invention the first line comprises a linear portion and a coupling element coupling the linear portion to the first radiating element and the second line has a linear portion and a coupling element coupling the linear portion to the second element.

[0006] The single-element antenna system provides the basic structure for antenna array systems, with potential applications in a) modern communication systems, such as personal communication systems, mobile satellite communications, wireless local area networks (WLANs), direct broadcast television (DBS), automotive radar systems, and b) military applications, such as wideband phased arrays for radar applications, ECM equipment, conformal phased arrays for telemetry systems, wideband jammers.

[0007] Embodiments of the invention offering further advantages are defined in dependent claims 2 to 10.

[0008] Claims 2 and 3 define preferred embodiments of the radiating elements: according to claim the projection of the dipole to either side of the dielectric substrate has a butterfly shape, with an axis of symmetry coinciding with the direction of the metal strip for supplying signals to and from said dipole. The butterfly shaped projection has a first dimension along the axis of symmetry and a second maximum dimension, normal to the first dimension, with the ratio of the second dimension over the first dimension being between 2.6 and 8. According to claim 3 this ratio is between 3.5 and 4.5.

[0009] Claims 4 to 5 defined advantageous embodiments of the invention including radiating elements with particular features.

[0010] The tangents of the periphery of the first radiating element and the second radiating element at their intersections with the axis of symmetry is oblique to the direction normal to the axis of symmetry at an angle, which according to claim 6 is between 10° and 50°. In a further embodiment, which defined in claim 7, this angle is preferably, between 25° and 42°.

[0011] Further preferred shapes of the coupling elements are defined in claims 8 and 9.

[0012] The antenna of claim 10 comprises a plurality of the antenna systems in accordance with the invention.

[0013] The invention will be now described by way of example and with reference to the accompanying drawings in which:

[0014] Figure 1 shows a perspective view of an antenna system according to the present invention.

[0015] Figure 2 shows a schematic top view of the antenna system shown of figure 1.

[0016] Figure 3 shows a cross-sectional view of the balanced microstrip line structure.

[0017] Figures 4a and 4b show a schematic top view of radiators including coupling (matching) elements.

[0018] Figures 5a and 5b show possible shapes of the radiating elements according to the invention.

[0019] Figure 6 shows a particular shape of the radi-

ating element.

[0020] FIG. 7 shows a top view of the proposed C band solution according to the present invention, including dimensions in mm.

[0021] Figure 8 shows the measured diagram of the input reflection coefficient of the antenna system shown in figure 7 as obtained using a scalar network analyzer.

[0022] Figure 9 shows a top view of the proposed butterfly antenna structure according to the present invention, including dimensions in mm.

[0023] Figure 10 shows the measured diagram of the input reflection coefficient of the antenna system shown in figure 9 as obtained using a scalar network analyzer.

[0024] Figure 11 shows an antenna array comprising the single-element antenna systems in accordance with the present invention.

[0025] Figure 12 shows the measured diagram of the input reflection coefficient of the antenna array shown in figure 11 as obtained using a scalar network analyzer.

[0026] The proposed antenna system consists of a butterfly shaped dipole (radiator) comprising two radiating elements, balanced microstrip lines and balanced-to-unbalanced transition (balun) for the feeding network. According to the invention the shape of the radiating elements is isosceles trapezium with its sides, i.e. the edges of the radiating elements, being straight or almost straight lines. The balun is made wideband enough, so that the antenna bandwidth is not restricted. The whole structure is printed on a low-loss dielectric substrate and is placed about a quarter wavelength above a metal reflector plate. The two radiating elements of the dipole are printed on the opposite side of the dielectric substrate. The proposed antenna system achieves wideband operation; bandwidth enhancement over the conventional dipole element, is achieved by the specific shape of the radiating elements, the proper matching between the feeding line and the radiating elements, through a coupling element, which may be a tapered or stepped balanced portion of the microstrip line, and the distance of the substrate from the ground plane (metal plate).

[0027] The wideband antenna system of figure 1 comprises a dielectric substrate 1, having a front face and a back face, a butterfly shaped dipole, having a first radiating element 2 for radiating and receiving electromagnetic signals printed on the front face of the dielectric substrate 1, and a second radiating element 3 for radiating and receiving electromagnetic signals printed on the back face of the dielectric substrate 1. The first radiating element 2 points in a first direction and the second radiating element 3 points in a second direction, which is opposite to that first direction. Further metal strip means is provided for supplying signals to and from the dipole with the metal strip means having a first line 4 adjacent the radiating element, printed on the front face of the substrate 1 and coupled to the first radiating element 2 and a second line 5 printed on the back face of the substrate 1 and coupled to the second radiating element 3. The first line 4 has a linear portion with constant cross-section and a coupling element 10 adjacent the radiating element, coupling the linear portion to the first radiating element 2. Similarly the second line 5 has a linear portion with constant cross-section and a coupling element 10 coupling the linear portion to the second radiating element 3. A reflector 6 is located at a distance H parallel to the back face of the dielectric substrate 1. Air or a low loss material 7 is provided between reflector 6 and the back face of the substrate 1. The first and second lines are balanced and arranged parallel and opposite to each other on said front and back dielectric face, respectively. The antenna system according to the present invention includes a transition element coupled to the first line 4 and the second line 5 to provide a transition between the first and second lines and the system front-end, for supplying signals to and from the antenna. The transition element comprises a first element 8 and a second element 9 coupled to the first line 4 and the to the second line 5 respectively.

[0028] The dipole according to the invention consists of the two radiating elements 2 and 3. In any of the figures 1, 2, 4a, 4b, 7, 10 it can be seen that the projection of the dipole on either face of the substrate 1 has a butterfly shape with an axis of symmetry 20, which coincides along the direction of the metal strip means 4, 5. The dimension of the butterfly along the axis of symmetry equals W, whereas its maximum dimension in a direction normal to the axis of symmetry is 2L. According to the invention $8 \geq 2L/W \geq 2.6$ and preferably $4.5 \geq 2L/W \geq 3.5$. Further the angle α defined i) by the tangent to the edge of the radiator at its intersection with the metal strip, and ii) the direction, which is normal to the metal strip lines 4, 5 and which coincides with the direction of the axis of symmetry 20, is preferably between 10° and 50°. Further advantages are offered when α is between 25° and 40°.

[0029] Figures 4a, 4b show an embodiment with the radiating elements 2, 3 being isosceles trapeziums, whereby its sides are straight lines of equal length. L is the radiator length, which is equal to the height of the trapezium, W is the width of the smaller base of the trapezium, and α is the angle between L and the adjacent side of the trapezium. The application of the proposed system in lower or higher frequency ranges is possible by up or down scaling these dimensions. Variation of the dielectric substrate 1 and the material 7 between the dielectric substrate 1 and the reflector metal plate 6 can influence the system performance. However, design parameters must be kept within the specified limits, in order to obtain wide impedance and gain bandwidth, while cross-polarization is kept in low level (<-20dB).

[0030] Wider impedance bandwidth may be achieved by increasing the distance H of the dielectric from the ground plane (see figure 1). In this way the radius of the antenna impedance locus on the Smith Chart decreases and the gain in higher frequencies is decreased. In order to increase the gain of the antenna in higher frequen-

cies, the distance from ground must be reduced, but in this case impedance bandwidth is reduced, and additional matching is needed. Therefore the distance has to be selected in such way so that by properly matching the antenna, impedance and antenna gain bandwidth can provide wideband operation. In accordance with the invention proper matching is achieved by providing coupling (matching) elements 10 which have the effect of reducing the radius of the impedance locus and moving its center to a point symmetrical to the axis of the real impedance on the Smith Chart. The coupling element 10 of figure 2 has a tapered portion. Figure 4a shows a matching element 10 with two portions having different widths, while the edges of the matching element 10 of figure 4b are curved. The coupling elements 10 are located adjacent the radiating elements 2, 3 and may be integral parts of the first and second lines 4, 5 respectively. Final trimming of the antenna system, according to specific needs, may require additional matching elements 11, as shown in figure 2.

[0031] According to the present invention, the edges of the trapezium-shaped radiating elements 2, 3 are straight or almost straight lines. Examples with radiating elements having curved edges are shown in figures 5a and 5b, 6 and 10. Figures 5a and 5b show radiating elements with edges being almost straight. In these cases the sides of the trapeziums may be approximated by an exponential or polynomial function, for example of the form $y = Ae^{ax} + b$ or $y = Ax^a + b$, where x is measured along the dimension L and y is normal thereto. Thus the radiating element of figure 5a has a concave shape and that of figure 5b has a convex.

[0032] Advantageously, the material at the corner formed between the side and the large base of the radiating elements of figure 6 is relieved and the two edges lines are connected by a portion of a circle 12 whose center 13 is located on plane of the radiating element, as indicated in figure 6. The resulting dipole is shown in figure 9.

[0033] A top view of the proposed antenna system for C band operation, which is similar to the one presented in figure 2, is shown in figure 7. Figure 7 includes the dimensions of the antenna in mm. As it can be seen L=12mm, 2L=24mm, W=6mm, 2L/W=4, $\alpha \cong 37°$. The structure is printed on a 0.81mm thick Rogers 4003 (registered trademark) dielectric substrate with dielectric constant e_r=3.38. Plastic spacers are used to place the dielectric 24mm above a metal reflector plate. Figure 8 shows the measured results of the input reflection coefficient of the antenna system of figure 7; as it can be seen, the antenna according to the present invention shows wideband operation (bandwidth = 1 octave for $S_{11} \leq$ -15dB, for the frequency range 3-6GHz). However, the antenna gain in higher frequencies is reduced due to splitting of the main lobe. The measured input reflection coefficient of the antenna system of figure 8 was obtained using a scalar network analyzer.

[0034] Wider antenna gain bandwidth with low cross-polarization level may be achieved with the antenna comprising the radiating element of figure 9 and reduced spacing from the reflector plate. The main dimensions of the radiating elements are: L=16mm, 2L=32mm, W=8mm, whereas the sides of the trapeziums follow the curve $y = 1.26x - e^{0.167x} + 5$, for $0 \leq x \leq 13.5$, and $(y-10)^2 + (x-13.5)^2 = 2.5^2$, for $13.5 \leq x \leq 16$. The height H of the substrate 1 from the reflector plate 6 equals H=20mm. Other dimensions of this example are presented in figure 10. The proposed system achieves wide bandwidth concerning impedance (frequency range 3.15-4.3GHz for $S_{11} \leq$ -15dB), antenna gain, cross-polarization and radiation pattern characteristics.

[0035] Application of the above single-element antenna system into a planar antenna array is shown in figure 11. The above system is optimized for minimum reflection coefficient ($S_{11} \leq$ -20dB) for the frequency range 3.4-4 GHz (figure 12).

Claims

1. Antenna system comprising a) a dielectric substrate (1) with a front and a back dielectric face, b) a dipole with a first radiating element (2) for radiating and receiving electromagnetic signals, said first radiating element (2) being printed on the front face of the dielectric substrate (1), and a second radiating element (3) for radiating and receiving electromagnetic signals, said second radiating element (3) being printed on the back face of the dielectric substrate (1), c) a metal strip for supplying signals to and from the dipole, said metal strip having a first line (4) coupled to the first radiating element (2) and a second line (5) coupled to the second radiating element (3), **characterized in that** the first line (4) comprises a linear portion and a coupling element (10) coupling the linear portion to the first radiating element (2), and **in that** the second line (5) has a linear portion and a coupling element (10) coupling the linear portion to the second element (3).

2. Antenna system according to claim 1, whereby the projection of the dipole (2, 3) to either side of the dielectric substrate has a butterfly shape having an axis of symmetry, which coincides with the direction of the metal strip (4, 5) for supplying signals to and from said dipole (2, 3), with the butterfly shaped projection having a first dimension along the axis of symmetry and a second maximum dimension, normal to the first dimension, and whereby the ratio of the second dimension over the first dimension being between 2.6 and 8.

3. Antenna system according to claim 1, whereby the projection of the dipole (2, 3) to either side of the dielectric substrate has a butterfly shape having an axis of symmetry, which coincides with the direction

of the metal strip (4, 5) for supplying signals to and from said dipole (2, 3), with the butterfly shaped projection having a first dimension along the axis of symmetry and a second maximum dimension, normal to the first dimension, and whereby the ratio of the second dimension over the first dimension being between 3.5 and 4.5.

4. Antenna system according to any of the claims 1 to 3, whereby the first radiating element and the second radiating element are isosceles trapeziums.

5. Antenna system according to claim 4, whereby the sides of the isosceles trapeziums are curved, so that the first radiating element (2) and the second radiating element (3) have a concave or convex shape.

6. Antenna system according any of claims 1 to 5, whereby the projection of the dipole (2, 3) to either side of the dielectric substrate has a butterfly shape having an axis of symmetry, which coincides with the direction of the metal strip (4, 5) for supplying signals to and from said dipole (2, 3), with the butterfly shaped projection having a first dimension along the axis of symmetry and a second maximum dimension, normal to the first dimension, and whereby the tangents of the periphery of the first radiating element (2) and the second radiating element (3) at their intersections with first line (4) and the second line (5) respectively, are oblique to the direction, which direction is normal to the first line (4) and second line (5) at an angle, which angle is between 10° and 50°.

7. Antenna system according any of claims 1 to 5, whereby the projection of the dipole (2, 3) to either side of the dielectric substrate has a butterfly shape having an axis of symmetry, which coincides with the direction of the metal strip (4, 5) for supplying signals to and from said dipole (2, 3), with the butterfly shaped projection having a first dimension along the axis of symmetry and a second maximum dimension, normal to the first dimension, and whereby the tangents of the periphery of the first radiating element (2) and the second radiating element (3) at their intersections with first line (4) and the second line (5) respectively, are oblique to the direction, which direction is normal to the first line (4) and second line (5) at an angle, which angle is between 25° and 42°.

8. Antenna system according to any of the claims 1 to 7, whereby both the coupling element (10) of the first line (4) and the coupling element (10) of the second line (5) have tapered portions.

9. Antenna system according to any of the claims 1 to 8, whereby each one of the coupling element (10) of the first line (4) and the coupling element (10) of the second line (5) has distinct parts with different widths.

10. Antenna comprising a plurality of the antenna systems of any of the preceding claims 1 to 9.

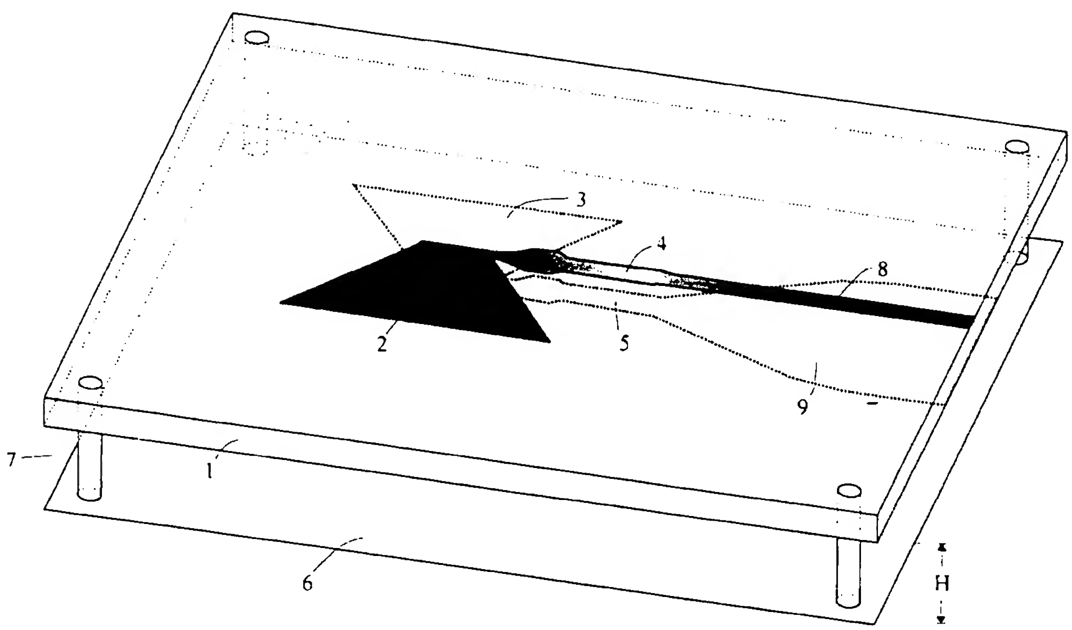

FIG. 1

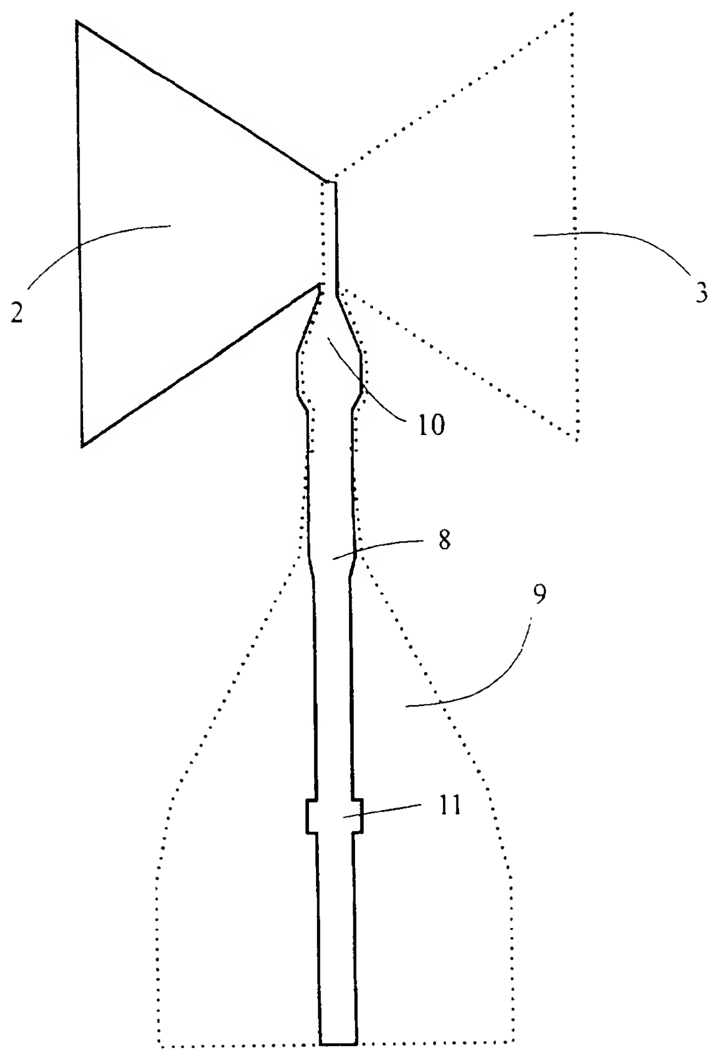

FIG. 2

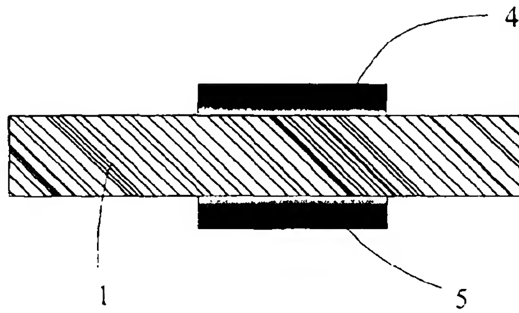

FIG. 3

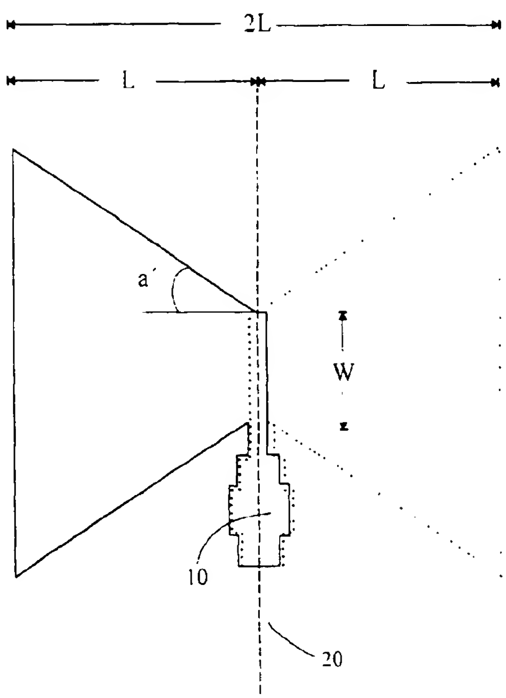

FIG. 4a

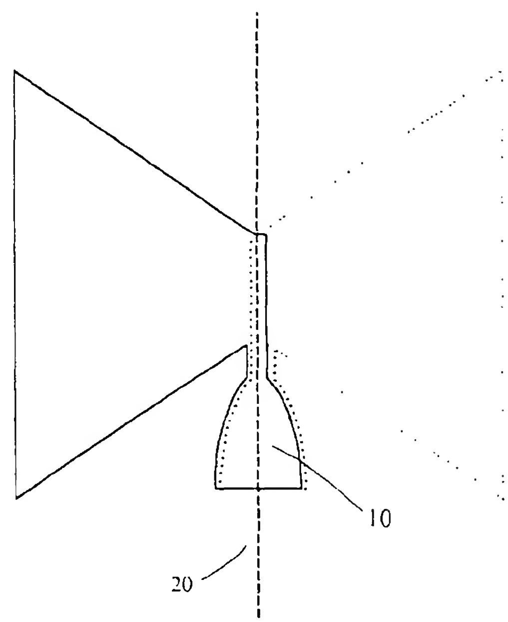

FIG. 4b

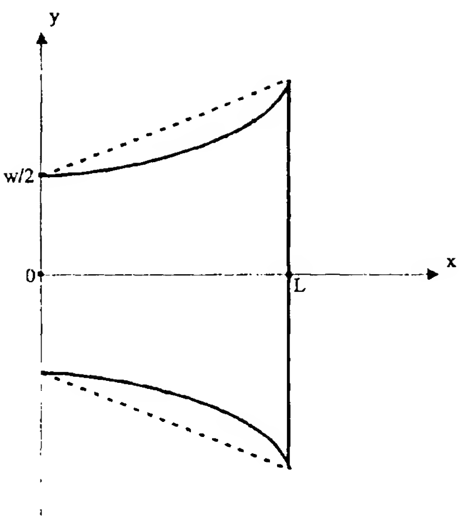

FIG. 5a

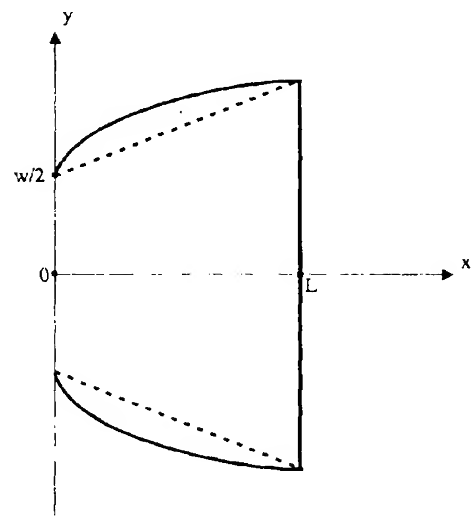

FIG. 5b

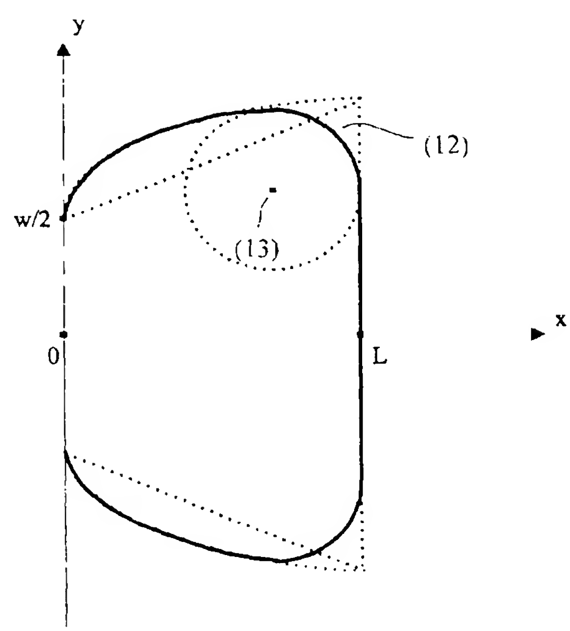

FIG. 6

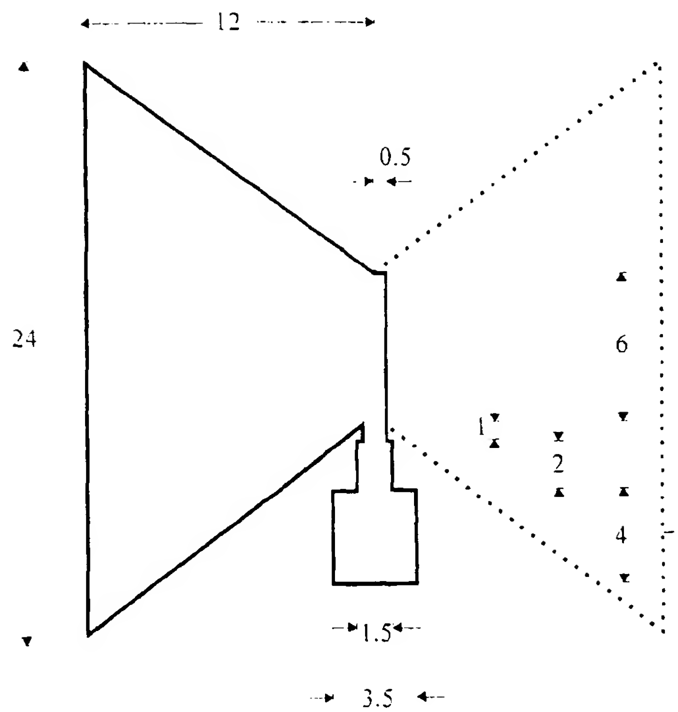
12
0.5
24
6
1
2
4
1.5
3.5

FIG. 7

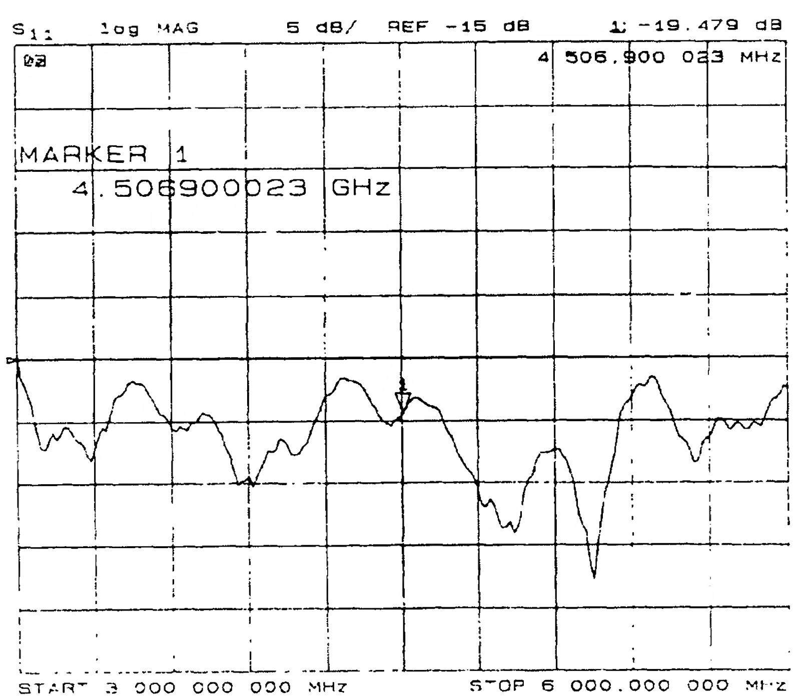
S11 log MAG 5 dB/ REF -15 dB 1: -19.479 dB
4 506.900 023 MHz
MARKER 1
4.506900023 GHz
START 3 000 000 000 MHz
STOP 6 000.000 000 MHz

FIG. 8

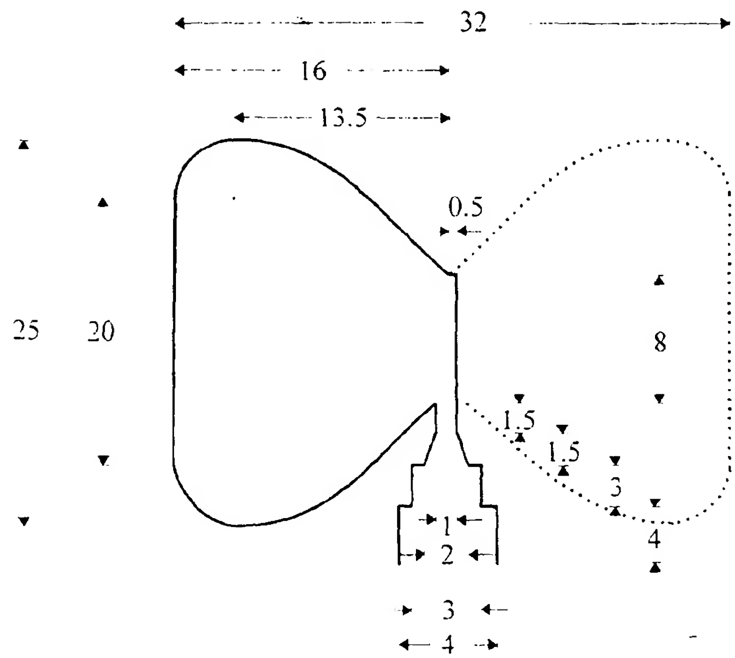
32
16
13.5
0.5
25
20
8
1.5
1.5
3
4
1
2
3
4

FIG. 9

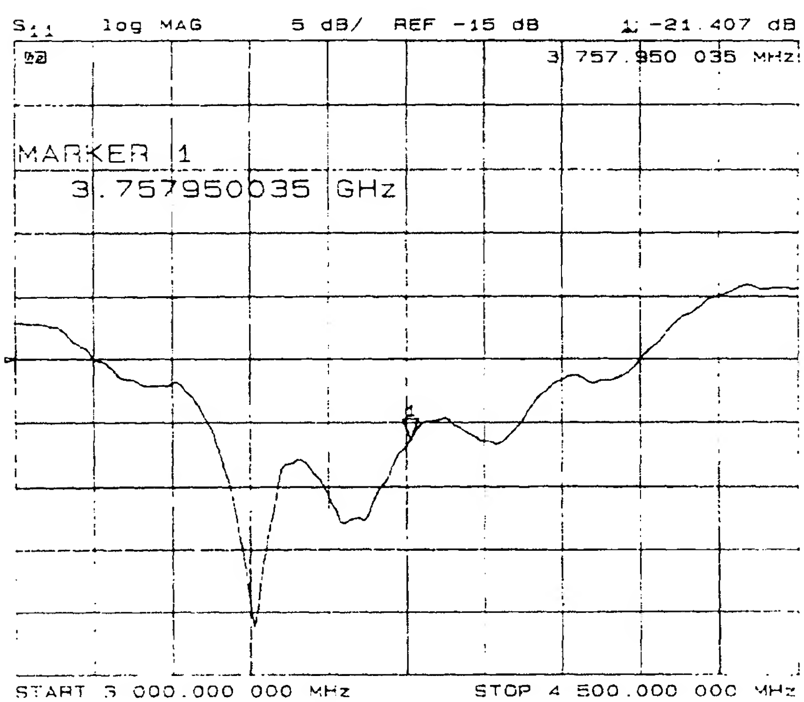
S11 log MAG 5 dB/ REF -15 dB 1: -21.407 dB
3 757.950 035 MHz
MARKER 1
3.757950035 GHz
START 3 000.000 000 MHz
STOP 4 500.000 000 MHz

FIG. 10

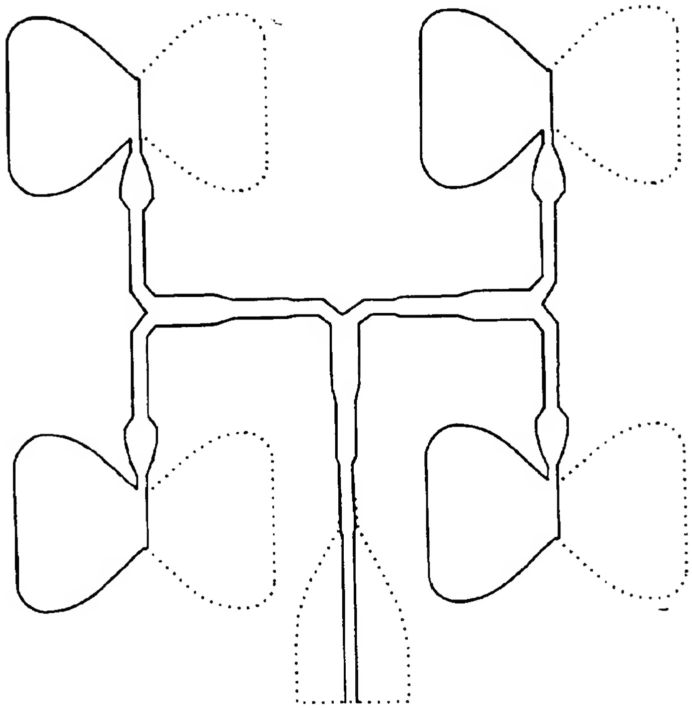

FIG. 11

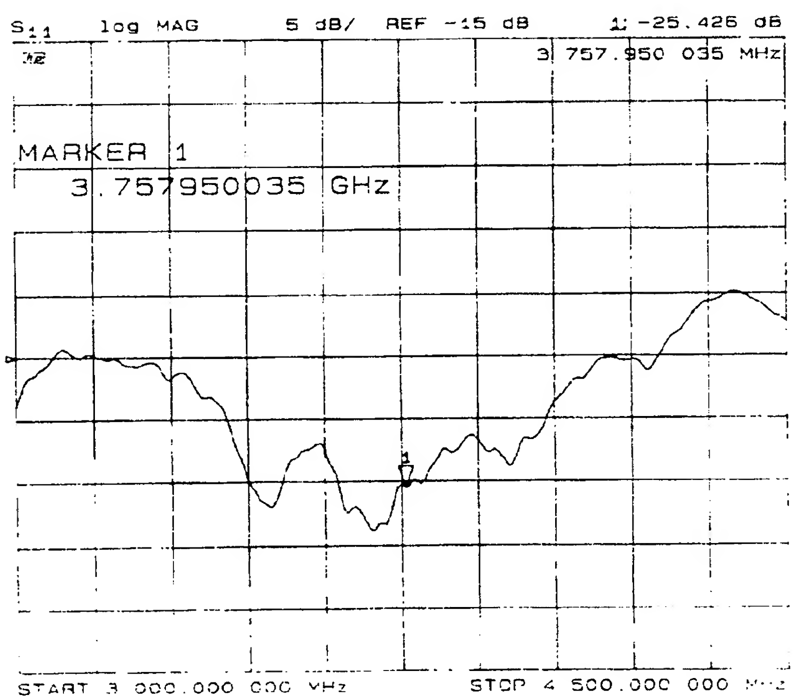
S11 log MAG 5 dB/ REF -15 dB 1: -25.426 dB
3 757.950 035 MHz
MARKER 1
3.757950035 GHz
START 3 000.000 000
STOP 4 500.000 000

FIG. 12

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 60 0007

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	XUE FENGZHANG: "A BROADBAND PRINTED CIRCUIT ANTENNA WITH STRIP GRIDS" PROCEEDINGS OF THE ANTENNAS AND PROPAGATION SOCIETY ANNUAL MEETING. 1991. VENUE AND EXACT DATE NOT SHOWN, NEW YORK, IEEE, US, vol. 1, 1991, pages 154-157, XP000242407 ISBN: 0-7803-0144-7 * page 154, line 21 - line 33 * * page 155, line 13 - line 22; figures 1,2 * ---	1-10	H01Q9/28 H01Q9/06 H01Q1/38
X	SUPRIYO DEY: "BANDWIDTH ENHANCEMENT BY FLARED MICROSTRIP DIPOLE ANTENNA" PROCEEDINGS OF THE ANTENNAS AND PROPAGATION SOCIETY ANNUAL MEETING. 1991. VENUE AND EXACT DATE NOT SHOWN, NEW YORK, IEEE, US, vol. 1, 1991, pages 342-345, XP000242446 ISBN: 0-7803-0144-7 * page 342, line 21 - line 29; figure 1 * ---	1-7	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
X	EVTIOUSHKINE G A ET AL: "Very wideband printed dipole antenna array" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 34, no. 24, 26 November 1998 (1998-11-26), pages 2292-2293, XP006010649 ISSN: 0013-5194 * page 2292, left-hand column, line 1 - line 3; figures 1,3 * ---	1-3,6-10	H01Q
	-/--		

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 September 2001	Moumen, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

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EUROPEAN SEARCH REPORT

Application Number
EP 01 60 0007

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	DEY S ET AL: "Analysis of cavity backed printed dipoles" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 30, no. 3, 3 February 1994 (1994-02-03), pages 173-174, XP006000134 ISSN: 0013-5194 * page 173, left-hand column, line 22 - line 32; figure 1 * -----	4	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons
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